

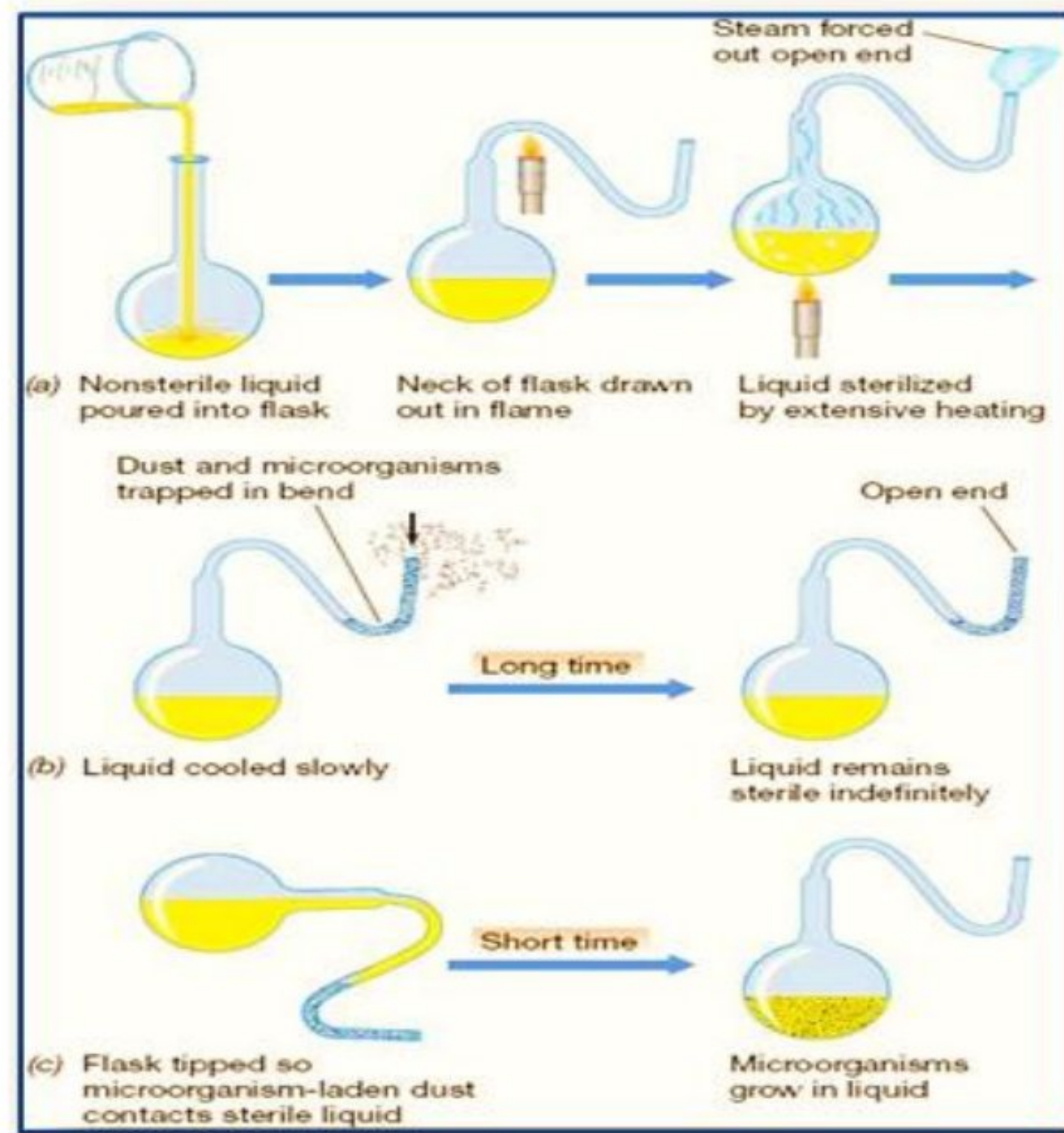
INTRODUCTION TO MICROBIOLOGY

Microbiology is the field of science that deals with the study of organism, called microorganisms, so small that they can be observed only under microscope. The development of microbiology began only from last century when the world started to appreciate the role of unseen microorganisms in the processes such as decomposition and disease.

- Microorganisms are the most primitive life on earth but were discovered very late. The discovery became possible only after the invention of the microscope. **Robert Hooke in 1665** invented the first microscope and observed the fruiting structure of mold. **Antony van Leeuwenhoek in 1674** was the first person to see and observed prokaryotes. He sent his finding to the royal society of London.
- Microbiology did not develop as a science until the 19th century because proper techniques to study microbes were not available. Its growth started when scientist worked on **the spontaneous generation theory** and the nature of contagious diseases.
- With the development of better methods and the electron microscope, smaller microbes like viruses were discovered. Recombinant DNA technology further led to rapid progress in microbiology. Today it has a central place in biological studies.
- The scope of microbiology is very wide. It is applied in **medicine, industry, and ecology**.

Spontaneous generation (abiogenesis), Biogenesis

- Spontaneous Generation Theory was the belief from the time of Aristotle (334-322 BC) that living organisms develop spontaneously from non-living or decaying matter. This was also called the theory of abiogenesis and was widely accepted till the 18th century.
- The first challenge to this theory came from Francesco Redi (1626-1697) in the 17th century. He placed meat in three containers - one closed with cloth, one with paper, and one uncovered. Maggots appeared only in the uncovered container. This proved that maggots came from fly eggs and not from the meat itself.
- In the mid-18th century, Lazzaro Spallanzani (1729-1799) showed that putrefaction was caused by microorganisms that multiply by division and not by spontaneous generation. He boiled sealed flasks containing meat, which destroyed the microbes and prevented spoilage.
- The theory was finally disproved by Louis Pasteur (1822-1895). His work marked the beginning of microbiology. In 1857 he studied lactic acid fermentation and showed it was due to bacteria. In 1860 he gave the first example of synthetic medium for growing microorganisms. In 1861 he proved that fermentation required yeast cells, and that more than one organism could be present in a culture. He also discovered anaerobic life and the "Pasteur effect".
- Pasteur's most famous experiment used the swan neck flask in 1861. He showed that sterile broth remained clear unless air containing contaminants entered it. This proved microorganisms come from air. He also introduced 'Pasteurization' to sterilize liquids.



Swan neck flask Experiment

- John Tyndall, an admirer of Pasteur, found that some bacteria survived boiling because they formed heat-resistant endospores. He developed 'Tyndallization' - intermittent heating to kill endospores vegetative cell.
- During the same period botanist named Cahn described endospores and their heat stable properties, Tyndall therefore devised a procedure for destroying the endospore, called Tyndallization.

Germ Theory of Disease, Koch's Postulates:

- Till the 17th century, people believed diseases were caused by supernatural forces, poisonous vapors called miasmas, and imbalance of body humors.
- The idea that invisible organisms cause disease was suggested earlier, but the first proof came from Agostino Bassi (1773-1856) who showed that a silkworm disease was due to fungal infection.
- Joseph Lister (1827-1912), a supporter of Pasteur, proved the role of microorganisms in wound infections. In 1867 he showed that treating surgical instruments with disinfectants prevented post-operative infections.
- Jacob Henle (1809-1885), a professor of anatomy and advocate of the germ theory of disease, proposed that living organized matter gets transmitted through air or by contact and thus multiplies in the body.
- Robert Koch (1843-1910) used the same basis proposed by his teacher Henle, to establish the relationship between *Bacillus anthracis* and anthrax.
- The final proof for the germ theory of disease was later given by Robert Koch, establishing that specific microorganisms cause specific diseases.

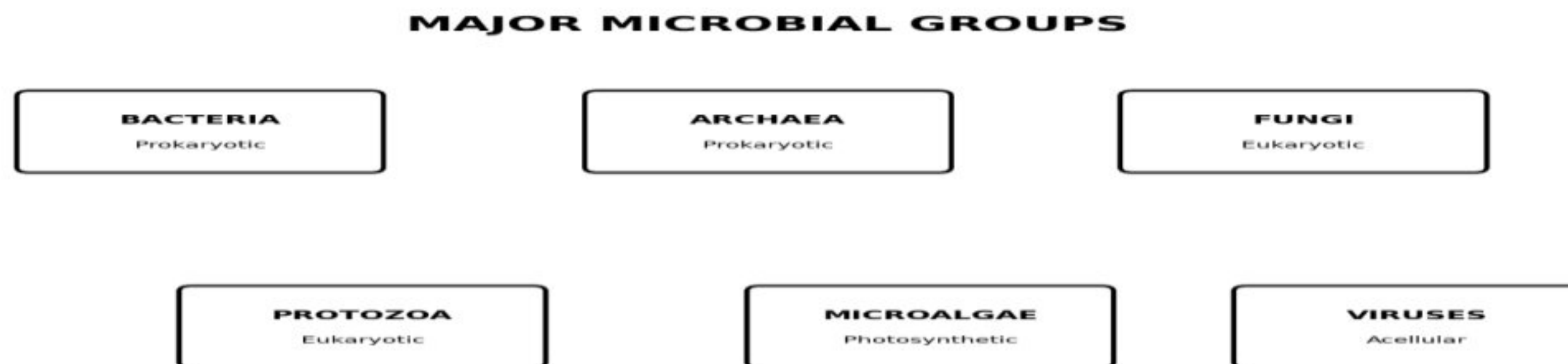
- Koch described the steps that were necessary, called Koch's postulates,

Koch's postulates:

1. The microorganisms should be present in every animal suffering from disease and they should be absent in healthy animals.
2. The disease producing organisms should be isolated and grown in pure culture.
3. When such isolated (disease producing) organisms are inoculated into a healthy susceptible host, the disease should result.
4. The same organism must be reisolated from the diseased host.

The philosophy of Koch's postulate for identifying the causes of infectious disease.

MICROORGANISMS IN THE BIOLOGICAL WORLD



Microorganisms are microscopic organisms or biological entities that are generally too small to be seen clearly with the naked eye. They occur in soil, water, air, food, plants, animals, and extreme environments. Their enormous biochemical diversity allows them to carry out processes such as respiration, fermentation, photosynthesis, decomposition, nutrient cycling, and synthesis of useful compounds.

For biochemistry students, microorganisms are important because they provide excellent systems for studying enzymes, metabolic pathways, DNA replication, transcription, translation, gene regulation, protein synthesis, fermentation, and recombinant DNA technology.

Microorganisms are not synonymous with disease. Many microorganisms are beneficial and are essential to ecosystems, food production, biotechnology, and human health.

Major Groups of Microorganisms

The microbial world contains both cellular and acellular entities. Cellular microorganisms include prokaryotes such as bacteria and archaea and eukaryotic microorganisms such as fungi, protozoa, and microscopic algae. Viruses are acellular infectious agents and are commonly studied alongside microorganisms because of their microscopic size and biological importance.

- Bacteria – unicellular prokaryotic organisms.

- Archaea – prokaryotic organisms with distinctive membrane and molecular characteristics.
- Fungi – eukaryotic organisms including yeasts and moulds.
- Protozoa – mostly unicellular eukaryotic organisms.
- Microscopic algae – photosynthetic microorganisms, especially important in aquatic ecosystems.
- Viruses – acellular infectious agents that require host cells for replication.

The three-domain system divides cellular life into Bacteria, Archaea, and Eukarya. Bacteria and Archaea are prokaryotic because they lack a membrane-bound nucleus. Eukarya contains cells with a true nucleus and membrane-bound organelles.



THREE DOMAINS OF CELLULAR LIFE

Domain	Cell type	Key features	Examples
Bacteria	Prokaryotic	Usually peptidoglycan; 70S ribosomes	E. coli, Bacillus
Archaea	Prokaryotic	Ether-linked membranes; no peptidoglycan	Methanogens, halophiles
Eukarya	Eukaryotic	Nucleus and membrane-bound organelles	Yeast, protozoa, algae

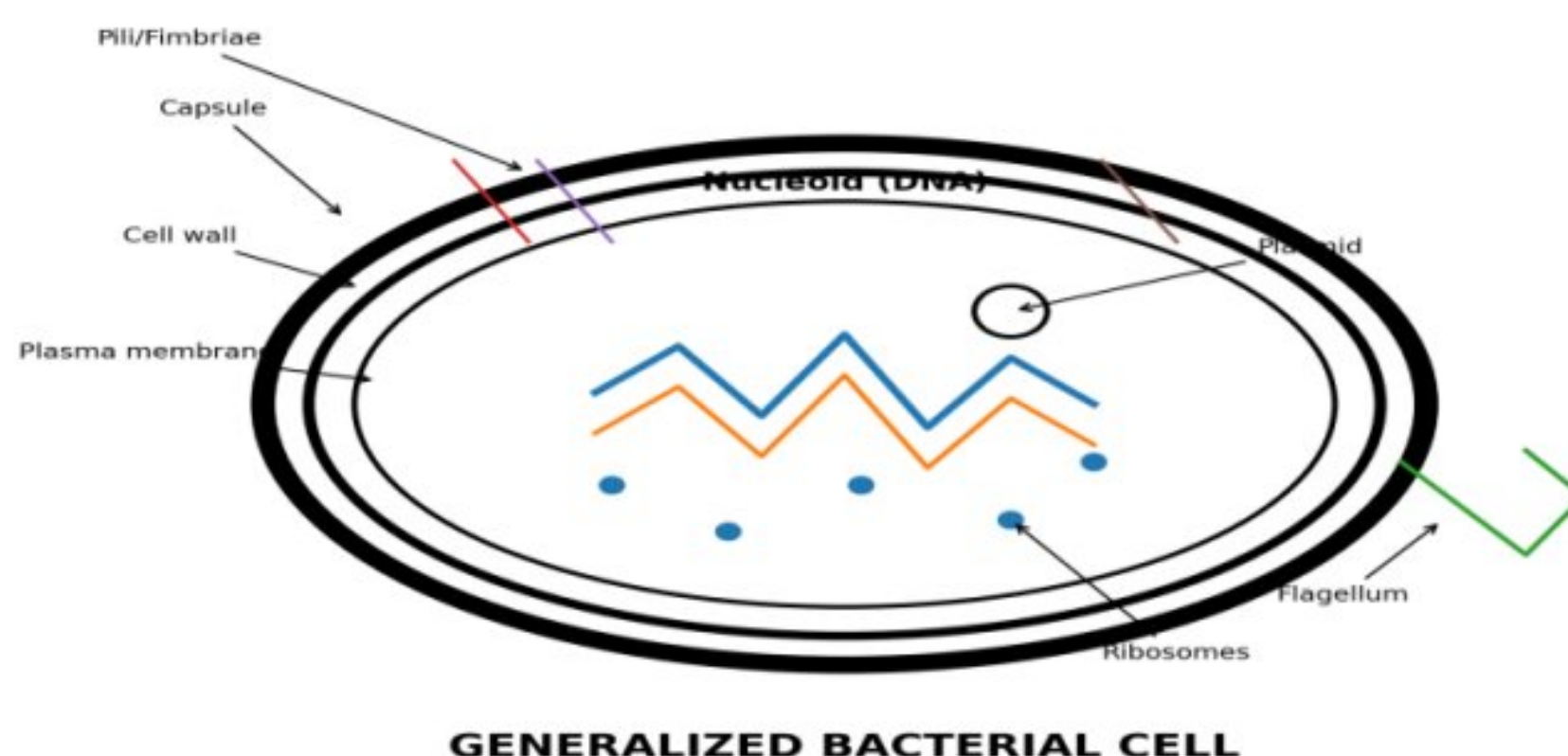
Prokaryotic Microorganisms

Prokaryotic cells are generally small and lack a membrane-bound nucleus and typical membrane-bound organelles such as mitochondria and endoplasmic reticulum. Their genetic material is located mainly in the nucleoid. Despite their simple organization, prokaryotes possess highly coordinated biochemical systems for energy generation, biosynthesis, replication, and environmental adaptation.

- Usually unicellular.
- No membrane-bound nucleus.
- DNA concentrated in the nucleoid.
- Generally contain 70S ribosomes.
- Many have cell walls.
- Bacteria commonly reproduce by binary fission.
- Show remarkable metabolic diversity.

Bacterial Cell Structure

A typical bacterial cell contains a plasma membrane, cytoplasm, nucleoid, ribosomes, and usually a cell wall. Some bacteria also possess capsules, flagella, pili/fimbriae, plasmids, or other specialized structures.



Capsule or slime layer

Often polysaccharide-rich; can protect from desiccation, aid attachment, and contribute to biofilms and pathogenicity.

Cell wall

Provides shape and mechanical protection. In most bacteria it contains peptidoglycan.

Plasma membrane

Controls transport and is an important site of electron transport, energy conservation, ATP synthesis, and biosynthetic reactions.

Cytoplasm

Contains enzymes, metabolites, ions, ribosomes, DNA, and other cellular components.

Nucleoid

Region containing the principal bacterial chromosome, generally a circular DNA molecule.

Ribosomes

70S ribosomes responsible for protein synthesis; composed of 30S and 50S subunits.

Flagella

Locomotory structures found in many motile bacteria.

Pili/fimbriae

Surface appendages involved mainly in attachment and, in some bacteria, DNA transfer.

Plasmids

Small extrachromosomal DNA molecules that may carry genes for antibiotic resistance or specialized functions.

Bacterial Shapes

Bacterial morphology is useful for preliminary identification. Common shapes include:

- Cocci – spherical cells.
- Bacilli – rod-shaped cells.
- Vibrios – curved or comma-shaped cells.
- Spirilla – rigid spiral-shaped cells.
- Spirochetes – flexible spiral-shaped cells.

Gram-Positive and Gram-Negative Bacteria

Gram staining distinguishes major bacterial groups according to differences in cell-envelope structure. Gram-positive bacteria generally have a thick peptidoglycan layer and stain purple. Gram-negative bacteria have a thin peptidoglycan layer plus an outer membrane containing lipopolysaccharide (LPS), and they generally stain pink or red.

Feature	Gram-positive	Gram-negative
Peptidoglycan	Thick	Thin
Outer membrane	Absent	Present
Teichoic acids	Usually present	Absent
LPS	Absent	Present
Gram-stain appearance	Purple	Pink/red

Biochemical significance: Lipid A, a component of Gram-negative LPS, is responsible for much of the endotoxin activity associated with these bacteria.

Archaea

Archaea are prokaryotic microorganisms belonging to a domain distinct from Bacteria. Their membranes contain ether-linked lipids, and their cell envelopes do not contain bacterial peptidoglycan. Some archaea live in extreme environments, while others occur in ordinary soils, oceans, and animal-associated environments.

- Methanogens – produce methane under anaerobic conditions.
- Halophiles – adapted to high salt concentrations.
- Thermophiles/hyperthermophiles – grow at high temperatures.
- Acidophiles – prefer acidic environments.

Methanogens are important in anaerobic ecosystems, wetlands, ruminant digestion, and biogas production. A simplified reaction is $\text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O}$.

Extremophiles

Extremophiles are microorganisms capable of growth under environmental conditions that are extreme for many other organisms. Their proteins, membranes, and metabolic systems possess adaptations that maintain biochemical function under these conditions.

- Psychrophiles – cold-loving microorganisms.
- Thermophiles – heat-loving microorganisms.
- Halophiles – salt-loving microorganisms.

- Acidophiles – acid-loving microorganisms.
- Alkaliphiles – alkaline-loving microorganisms.

Extremozymes are enzymes obtained from extremophiles and can be valuable in industrial biotechnology because they function under unusual temperature, pH, or salt conditions.

Eukaryotic Microorganisms

Eukaryotic microorganisms contain a membrane-bound nucleus and membrane-bound organelles. Important microbial eukaryotes include fungi, protozoa, and many microscopic algae. Their organization is more complex than that of bacteria and archaea.

- Fungi – yeasts and moulds.
- Protozoa – mostly unicellular eukaryotic organisms.
- Microscopic algae – photosynthetic microorganisms important in aquatic ecosystems.

Fungi: Yeasts and Moulds

Fungi are eukaryotic organisms that generally obtain nutrients by absorbing organic compounds. Yeasts are usually unicellular, whereas moulds grow as filaments called hyphae. A network of hyphae is called a mycelium.

Yeasts

Saccharomyces cerevisiae is an important yeast used in bread making and fermentation. It commonly reproduces by budding and is also a major model organism for studying eukaryotic biochemistry.

Moulds

Moulds such as *Aspergillus*, *Penicillium*, and *Rhizopus* form filamentous mycelia. They participate in decomposition and have important food, pharmaceutical, and industrial applications.

Protozoa

Protozoa are generally unicellular eukaryotic microorganisms. Older classifications often grouped them by locomotory structures, although modern taxonomy emphasizes evolutionary relationships.

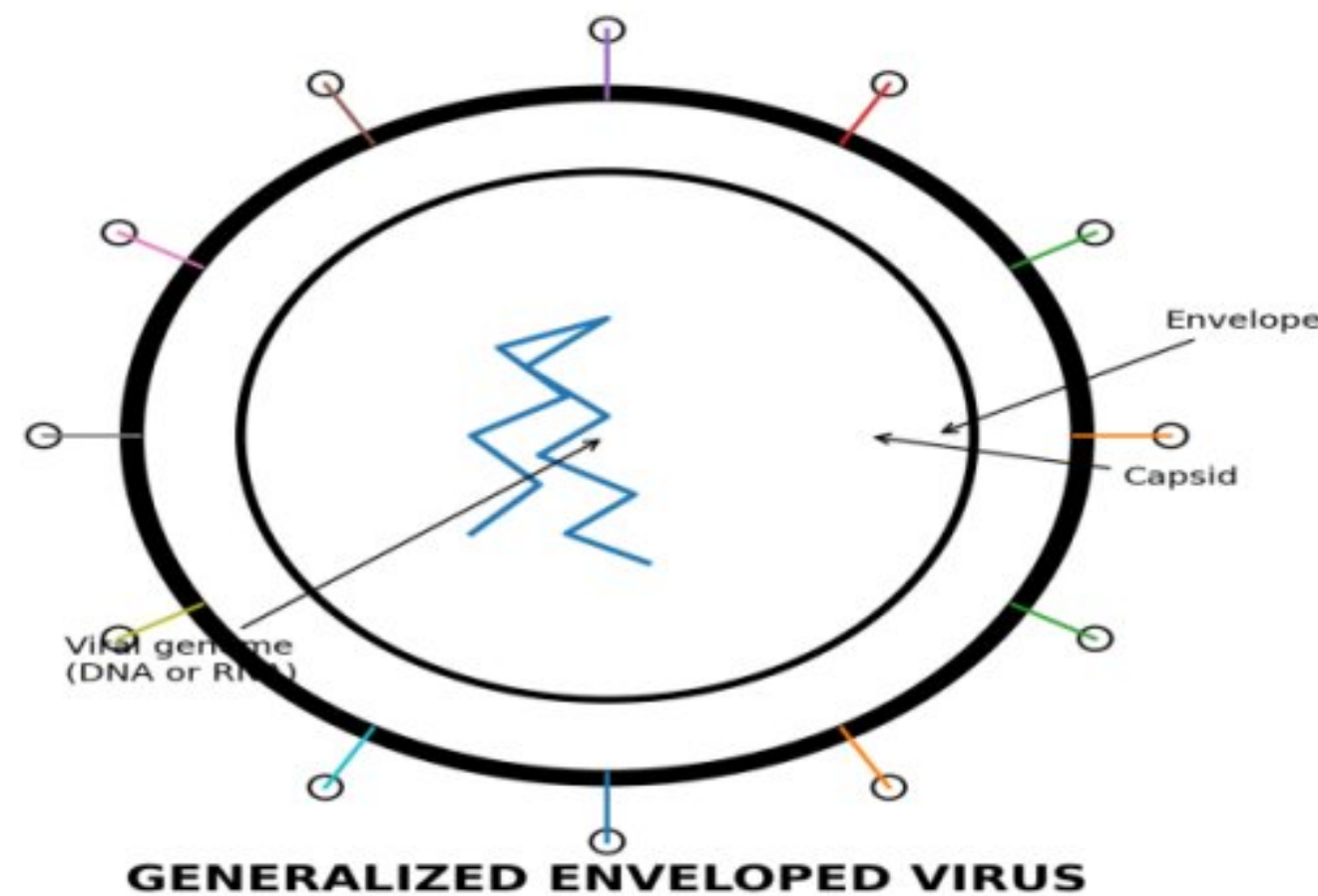
- Amoeboid forms – move using pseudopodia.
- Flagellates – move using flagella.
- Ciliates – move using cilia.
- Apicomplexans – include important parasites such as *Plasmodium*.

Microscopic Algae

Microalgae are photosynthetic microorganisms that capture light energy and fix carbon. They are especially important in aquatic ecosystems because they contribute to primary production, oxygen generation, and carbon cycling. The term microalgae is mainly functional rather than a single modern taxonomic group.

Viruses

Viruses are acellular infectious agents. They do not possess complete independent cellular metabolism and cannot reproduce by ordinary cellular division. They depend on host cells to replicate their genomes and produce viral proteins.



- Genome – DNA or RNA.
- Capsid – protein shell surrounding the genome.
- Envelope – lipid membrane present in some viruses.
- Nucleocapsid – genome together with its capsid.

Basic viral replication sequence

- Attachment
- Entry
- Uncoating
- Genome replication
- Viral protein synthesis
- Assembly
- Release

Viroids and Prions

Viroids are small infectious RNA molecules, generally circular single-stranded RNA, especially associated with plant diseases. They lack a protein capsid. Prions are infectious abnormal protein conformations that contain no conventional nucleic-acid genome and are associated with certain neurodegenerative diseases.

Prion concept: an abnormal protein conformation can promote abnormal folding of other protein molecules, leading to accumulation of misfolded protein.

Microbial Nutrition and Metabolic Diversity

Microorganisms require nutrients for energy production, biosynthesis, growth, repair, and maintenance. Their metabolic diversity is one of the most important features of microbial life.

- Macronutrients include carbon, hydrogen, oxygen, nitrogen, phosphorus, sulfur, potassium, magnesium, calcium, and iron.
- Micronutrients such as zinc, copper, manganese, cobalt, nickel, and molybdenum are often required as enzyme cofactors.
- Phototrophs obtain energy from light; chemotrophs obtain energy from chemical compounds.
- Autotrophs use CO₂ as a major carbon source; heterotrophs obtain carbon mainly from organic compounds.

Biochemistry link: Microbial metabolism includes catabolism, anabolism, respiration, anaerobic respiration, fermentation, and biosynthesis of cellular macromolecules.

Ecological Importance

Microorganisms are essential components of ecosystems. They decompose organic matter and recycle elements, thereby connecting living organisms with the chemical environment.

Carbon cycle

Microbial decomposition releases CO₂. Some microorganisms fix CO₂ into organic matter, while methanogens produce methane under anaerobic conditions.

Nitrogen cycle

Microorganisms carry out nitrogen fixation, ammonification, nitrification, and denitrification.

- Nitrogen fixation: $N_2 \rightarrow NH_3/NH_4^+$
- Ammonification: organic nitrogen $\rightarrow NH_3/NH_4^+$
- Nitrification: ammonia $\rightarrow$ nitrite $\rightarrow$ nitrate
- Denitrification: nitrate $\rightarrow N_2$

Sulfur cycle

Microorganisms oxidize and reduce sulfur compounds, including sulfate, sulfide, and elemental sulfur.

Human Microbiota

The human body supports complex microbial communities on the skin and in sites such as the oral cavity and gastrointestinal tract. The gut microbiota is especially relevant to biochemistry because microbial metabolism produces and modifies many compounds that can affect host physiology.

- Production of short-chain fatty acids.
- Transformation of bile acids.
- Production or modification of vitamins and other metabolites.
- Interaction with the immune system.
- Modification of dietary and host-derived molecules.

Food and Fermentation

Microorganisms have been used in food production for centuries. Controlled fermentation can improve preservation, flavor, texture, and other properties.

- Lactic acid bacteria – yogurt/curd, cheese, and fermented foods.
- *Saccharomyces cerevisiae* – bread and alcoholic fermentation.
- Selected fungi and bacteria – specialized fermented foods.

Uncontrolled microbial growth can cause food spoilage and foodborne illness, showing the dual importance of microorganisms in food.

Industrial and Medical Importance

Microorganisms function as biological factories. Their enzymes and metabolic pathways are exploited to manufacture useful products and to perform environmental processes.

- Antibiotics and antimicrobial compounds.
- Industrial enzymes.
- Organic acids such as lactic acid and citric acid.
- Amino acids and vitamins.
- Biofuels such as ethanol and biogas, Wastewater treatment and bioremediation
- Recombinant proteins.

Microorganism	Example application
<i>Saccharomyces cerevisiae</i>	Bread and ethanol fermentation
<i>Lactobacillus</i> spp.	Lactic acid fermentation
<i>Aspergillus niger</i>	Citric acid production
<i>Penicillium</i> spp.	Penicillin-associated production
<i>Escherichia coli</i>	Recombinant protein production

Microorganisms as Model Organisms

Microorganisms are valuable research systems because many grow rapidly, can be cultured under controlled conditions, and can be genetically manipulated. *E. coli* is widely used to study gene expression, DNA replication, transcription, translation, and recombinant DNA technology. *Saccharomyces cerevisiae* is a major eukaryotic model for cell cycle, genetics, metabolism, and intracellular trafficking.

Antimicrobial Resistance

Microorganisms can develop or acquire resistance to antimicrobial agents. Resistance may arise through mutation or acquisition of resistance genes and can spread between microorganisms through horizontal gene transfer.

- Drug inactivation.
- Alteration of drug targets.
- Reduced uptake or permeability.
- Active drug efflux.
- Alternative metabolic pathways.
- Acquisition of resistance genes.

Genetic Engineering and Biotechnology

Microorganisms are central to recombinant DNA technology. A gene of interest can be inserted into a suitable vector, introduced into a host microorganism, and expressed to produce a desired protein or metabolite.

Basic sequence: Gene of interest → DNA vector → Host microorganism → Gene expression → Desired product

24. Prokaryotes vs Eukaryotes

Feature	Prokaryotes	Eukaryotes
Nucleus	Absent	Present
Main DNA organization	Usually circular chromosome	Usually linear chromosomes
Cytoplasmic ribosomes	70S	80S
Mitochondria	Absent	Present
Endoplasmic reticulum	Absent	Present
Examples	Bacteria, archaea	Yeast, protozoa, algae

25. Bacteria vs Archaea

Feature	Bacteria	Archaea
Cell type	Prokaryotic	Prokaryotic
Peptidoglycan	Usually present	Absent
Membrane lipids	Ester-linked	Ether-linked
Methanogenesis	Absent	Present in methanogens
Genetic machinery	Bacterial type	Several features resemble eukaryotes